AN INTERACTIVE SIMULATION MODEL WITH GRAPHICS ANIMATION FOR SCHEDULING IN FMS

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by

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MARCH, 1987

CERTIFICATE

This is to certify that the work entitled, An Interactive Simulation Model with Graphics Animation for Scheduling in FMS, has been carried out by H.K. Madhusudhana under our supervision and has not been submitted elsewhere fo the award of a degree.

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ABSTRACT

In the present work, a simulation model for design and evaluation of scheduling strategies for an FMS has been developed. The model implementation has been done on ND-500 system.

The FMS modelled in this work consists of several work stations, each with its own input and output buffers of limited capacity. There is a central buffer of ample capacity to store semi-finished jobs. There is a loading station with its own buffer of sufficient capacity and an unloading station. The materials handling system in the model consists of a two-track, bidirectional conveyor with carts and robots. The model is capable of handling a known number of part types. These part types may possess alternative processing sequence. There may be alternative work-stations for some operations. The arrival of parts into the system is in a random manner and inter arrival time follows an exponential distribution.

A discrete event simulation model has been developed for the system described above using next event scheduling approach. A number of scheduling rules such as shortest imminent operation time, shortest remaining process time etc., have been incorporated in the model implementation. A combination of such rules can be used for decision making in such situations as successive

operation selection, machine selection, machine loading etc. Priority has been established to control movement and allocation of carts and robots, for better system utilization. For the purpose of evaluation of the system performance, performance criteria based on system productivity and system utilisation is chosen.

The package developed in this work provides animation of material flow in the system during simulation. The terminal features of Tektronix 4107/4109 has been utilised for this purpose.

Several experimental runs were designed and conducted to validate the model. The experiments were held for various scheduling strategies, with variations system configuration. The output from these experiments demonstrate the influence of physical sub-system and logic sub-system on the performance of an FMS.

Overall, the simulator can be used to simulate various design alternatives e.g., number of machining centres, number of carts, number of robots etc. The scheduling rules provided in the simulator can be used to evaluate the effectiveness of scheduling strategies in production control and to simulate what if scenarios in actual operation of FMS.

CHAPTER I

INTRODUCTION

The fundamental inputs to a manufacturing system are a inter-related mix of men, material, facilities, methods and information. The relative importance of each of these ingredients has under gone considerable changes representing varying states of technology. The present trend is towards automation of manufacturing systems to improve upon the system productivity. The NC and CNC machines were the earliest efforts in the development of automation concepts. Also there have been various kinds of material handling systems e.g. conveyors, robots, AGVs etc, with the development in technology. The concepts of automation has received a boost with the developments in computer technology. Due to the capacity of computers to process large quantity of information, it has been possible to organise the activities of a manufacturing system with little or no interference. A Flexible Manufacturing System (FMS) is the result of such integration of all these developments into a system which is more flexible and productive.

1.1 INTRODUCTION TO FMS CONCEPTS:

An FMS may be defined as a system with a high level of distributed data processing and automated material flow using computer controlled machines, assembly cells etc. together with computer integrated material handling and storage systems.

Generally an FMS combines the benefit of a highly productive, but inflexible transfer line and a flexible but inefficient job shop. An FMS basically incorporates individual automation concepts in a single production system. These are brought under computer control. In an ideal situation, such a system is capable of meeting any variations in product design, product volume. Such a system also works efficiently under disturbances like machine tool or transportation device break down. Scheduling in an FMS environment is dynamic and decisions are taken in real time.

1.2 FLEXIBILITY IN FMS:

The key aspect of an FMS is not the degree of automation it incorporates but its ability to adopt to changes. Though typical FMSs are highly automated, it is their ability to adopt to unpredictable and changing conditions which makes them flexible.

Though an FMS, in an ideal situtation, should be able to produce a part irrespective of its processing steps and their sequence, in practice flexibility in FMS is a relative term.

Generally an FMS offers the flexibility of the following types.

(i) Process Flexibility: This refers to the ability to choose an operation or a sequence of operations in more than one way. This also includes flexibility due to different routings, machine redundancy, tool redundancy etc.

(ii) Program Flexibility: This refers to the ability of the system to run virtually unmanned through a shift. This is possible to achieve when better sensors and computer controls are developed to take care of emergencies such as tool breakage, part congestion etc. This is enhanced with better understanding and knowledge of the system and the degree to which plans to take care of emergencies have been prepared.

(iii) Product Flexibility: An FMS is designed for low production volumes of few types of products initially, and new machines are added as demand increases. The product flexibility refers to the total incremental value of new products that can be produced with in the system for a defined cost of new fixtures, tools and part programs.

Present day FMSs provide rather limited product flexibility, relatively better process flexibility and program flexibility i.e. they can produce a limited number of part types, have ability to reroute the parts and provide alternative operations at some stage.

1.3 TREND IN FMS:

Flexible manufacturing systems in general, can be classified into the following two types:

(i) Dedicated FMS

(ii) Random FMS

Dedicated FMSs are such systems which have been designed to produce relatively small variety of product types which are

often quite similar. An FMS of the type is in operation in Yamazaki (Hartley (1983)).

Random FMSs are capable of producing a large variety of part types. Here the spectrum of parts that are being produced can be changed with little alteration. The parts arrive in a random fashion and may possess different operation sequences and process times.

The present trend is towards designing and installing random FMSs. Certain amount of progress has already been achieved in this direction. An FMS of this type is in operation at Fauncs Motor Manufacturing Division, Japan (Hartley (1983)). This system can produce a variety of components such as ac and dc motors, pumps, compressors etc.

Majority of FMSs at present are limited to machining operations only. Thus FMS exists as a part of a large manufacturing system. But efforts have been made to integrate machining welding and assembly operations into a single FMS. Such a system is in operation at Yamazaki, Japan.

1.4 FMS DESIGN TOOLS:

While considering the design of an FMS it is appropriate to consider FMS in two parts:

(i) Physical Subsystem: This consists of machine tools, materials handling equipment, buffers etc.

(ii) Control Subsystem: This forms the logic part of the system governing the operation of the physical subsystem. This consists

of rules about the introduction of parts into the system, assignment of machines to jobs, routing of parts, etc.

The two subsystems are inter-related and the total system performance is dependent on both the subsystems and hence must be considered in combination for FMS design.

With this in view the tools for FMS study can be divided into two divisions.

1. Analytical Tools: These are used in the preliminary design stage. The objectives here, are to arrive at an initial configuration of the system, to determine the components of the physical subsystem. Each of these components can be modelled separately and approximate solutions can be obtained. The concepts of linear programming and queuing theory have been found useful here.

2. Simulation Tools: To develop an appropriate and cost effective FMS one needs a design and planning tool that can consider the dynamic behaviour of the system. Here simulation has been found very useful. It allows one to describe an FMS design, and predict its performance without actually building the physical system. Variety of simulation tools are available and are used at different stages of design.

(i) Queuing Network Models: These are based on the standard queuing network theory and provide initial insight to the system performance.

(ii) Generalised Simulation Model: They are used for both design and operating stages of an FMS. This proves very useful in case

of non-steady state problems where analytical techniques are impractical.

(iii) Process Simulation or Emulation Model: Here the model runs into very great detail and provides detailed insight into the problem.

It must be mentioned here that with the developments in computer graphics techniques, simulation tools are accompanied in most cases by graphics animation of material flow in the system. Also the output of simulation presented graphically greatly enhances the understanding of the system.

The present work uses simulation technique for the study of FMS. The next section presents the basic concepts of simulation.

1.4.1 Simulation: A Tool in Design and Operation of FMSs:

Simulation, which started as a post marten tool to analyse the weakness of existing systems, of late has been widely used for the analysis of complex situations in industry and elsewhere. With the developments in flexible automation it has become more popular.

Simulation is a convenient tool to describe both physical and control subsystems of FMS. Hence the system behavior can be predicted and analysed very easily. It offers the following advantages.

(i) To study the effect of variations in system parameters, in the planning stage.

(ii) To evaluate control strategies and operating rules.

(iii) To study system behaviour under disturbance.

(iv) To detect bottle-neck conditions and develop corrective strategies during operation.

Another advantage is that when used with graphics animation, working of various design alternatives can be displayed.

Thus simulation provides comprehensive opportunity for the integration of design, planning and control functions, and is critical to the successful implementation of FMS.

CHAPTER II

LITERATURE SURVEY AND OBJECTIVES OF THE PRESENT WORK

2.1 LITERATURE SURVEY:

Simulation study of manufacturing systems has been one of the areas that has received wide attention. There are a number of models that have been developed to study the different aspects of FMS. Hence they differ in the characterization of the model, performance measures chosen, and the results presented. They differ in the capabilities of the model to handle various situations arising in an FMS environment. Some of these models are reviewed here.

G. Adner, G.A.H. Masus and C.G. Wikholm (1984) have developed a simulation model to study effect of layouts on systems performance. This model is capable of handling variable buffer sizes, machine tool break down, tool changing etc. However, this model can take care of production lines only, it fails in case when unrestricted flow of components exist between machines.

A model for FMS simulation developed by R. Manuelli and G. Guiducci (1984) considers FMS as made-up of physical components (i.e. machine tools) and logical components (i.e. queues at work station, statistics of the system). This model treats FMS as a closed system i.e. the number of pallets/parts in the

system is constant and every finished work piece is replaced by another work piece. The queue management in this system is by FIFO rule only.

Another aspect that has been investigated is the behaviour of the system under disturbances. Mehrtul and Portman (1985) have studied this aspect of FMS. They studied this problem using both analytical techniques and simulation techniques. The results from their study show that the results from the two methods differ greatly.

A simulation model for the purpose of development of control algorithms has been modelled by Z. Doulgari and R.D. Hibberd (1984). This model consists of work stations, individual buffers, central buffer cum loading/unloading station and palletised conveyor system. However this model does not consider non steady state problem like machine break down.

In an another work by K. Iwata et al (1984), they have developed a versatile model for FMS. This model considers FMS as consisting of work stations conveyors, warehouse, jigs and fixtures. This model provides graphics animation of material flow in addition to numerical output of the system. In an earlier work K. Iwata et al (1982) considered production scheduling problem in FMS using simulation. In this work, a simulation model was used to develop scheduling rules for FMS.

Although simulation has been used widely for the study of FMS, it is only recently that animation has been included to support the output of simulation. Animation of material flow supplemented by other graphical outputs such as histograms, charts etc. develop a better understanding of the system.

2.2 OBJECTIVES OF THE PRESENT WORK:

Simulation is an oftenly used tool for design evaluation and operational control of FMS. This imposes two important requirements on the simulation model. One is that it should be able to handle a variety of configurations of FMS. Another is that it should provide alternative strategies for control of FMS. Also the simulation results are better understood, if it is possible to visualise the working of the system. The present work is an attempt in this direction.

The objectives of this work can be listed as below:

(i) Model a flexible manufacturing system.

(ii) Provide a number of scheduling rules for operational control.

(iii) Implement the model in an interactive user friendly environment.

(iv) Provide the visual representation of the working of the model through animation.

(iv) Design performance criteria to evaluate the system performance and supplement the numerical output with histograms and bar charts.

2.3 ORGANISATION OF THE THESIS:

The organisation of this work is as follows.

In Chapter III, the development of the simulation model has been described. Here the process of development has been dealt in several sections, describing the characterisation of the model, assumptions involved and control strategies adopted. This chapter also presents the performance criteria chosen and event description.

In Chapter IV, the implementation aspects have been dealt in detail. This describes the simulator as several modules and their functions towards the working of the model.

The next chapter (Chapter V) deals with system validation. Here the system considered for experimentation is described and then various experiments have been mentioned. The results of these experiments have given in the next section along with output analysis.

The last chapter (Chapter VI) presents the conclusions arrived through this work, and gives suggestions for further development.

Appendix A gives sample out put of a simulation run.

Appendix B provides a user's manual, in which working details about the simulator has been given.

CHAPTER III

DEVELOPMENT OF SIMULATION MODEL

Model building for simulation is a continuous process. A model represents the real situation in an abstract way. To develop a model, it is necessary to start with certain assumptions limiting the scope and extent of the model. During the process of experiments, the results obtained add to the information, thus leading to the refinement of the model. During this process some assumptions may be removed and some others modified. It may also be necessary to add some more assumptions. An understanding of the assumptions play a vital role in the interpretation of results. Also the availability of data has a constraint on the model and the reliability of its results.

This chapter presents the description of the system being modelled in the present work, with associated assumptions. Further control logic used in the operation of the system is also being dealt in this chapter. Lastly the performance measures used for evaluation of the model are described.

3.1 SYSTEM DESCRIPTION:

The model considers FMS as consisting of the following components:

(i) Work stations with individual input and output buffers.

(ii) central buffer

(iii) One loading station and an unloading station.

(iv) Material handling system consisting of conveyor and robots.

The attributes of these component are mentioned below:

(i) Work Station: This defines the place where manufacturing activities are under taken. These could be locations for machining, metal working, inspection cleaning etc. These stations can accept one job at a time. Each of these stations is associated with an individual input and output buffers of limited capacity.

(ii) Central Buffer: This is the place for temporary storage of semi-finished parts, when a part finds the input buffer at its next work station full, it is taken to the nearest intermediate buffer, if present and stored there until the space becomes available. The central buffer is assumed to have ample capacity.

(iii) Materials Handling System: This consists of a conveyor with carts/pallets, and robots. Conveyor system transports parts between the stations on carts/pallets, it forms a closed loop and consists of two tracks allowing the movement in opposite directions. A cart/pallet can carry only one part at a time and moves at constant speed. Robot is also capable of transporting one part at a time. Speed of movement of robot is also constant.

(iv) Loading and Unloading Stations: Parts coming for processing enter

the system through the loading station which is associated with a loading buffer of large capacity. Unloading station is the place from where finished parts are taken away as soon as they are unloaded at this station.

A schematic representation of a typical FMS derived from the above description is shown in Fig. 1. The system consists of six work stations (M) along with individual input (I) and output (O) buffers. Conveyor system which is two track bi-directional (→←) forms the material handling system along with two robots (R). The system has a loading station (L) and an unloading station (U). A central buffer (I_m) is located midway in the system.

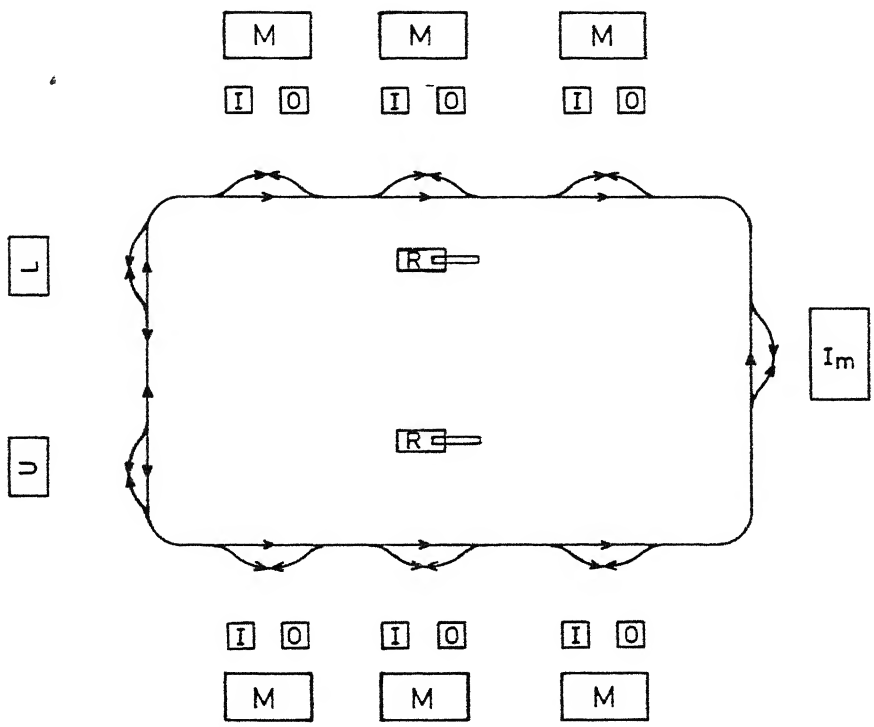
3.2 ASSUMPTIONS:

The following assumptions further characterise the model. This covers the behaviour of the components of the system and also the parts processed in it. They are:

a) Work Station

a.1) Each work station is self-sufficient i.e. they are provided with tool magazines of sufficient capacity and tools required are loaded on to them. Tool changing occurs automatically and requires negligible time. It is also implied here that tool transportation is not considered in the operation of the model.

a.2) It is possible that some of the operations can be done at more than one work stations. Operation time remains the same at



LEGEND M : MACHING CENTRE
I : INPUT - BUFFER
O : OUTPUT BUFFER
I_m: CENTRAL BUFFER
U : UNLOADING STATION
L : LOADING STATION
R : ROBOT

Fig. 1 Schematic layout of an FMS .

c.2) The total number of operations per part type is the sum of the all possible operations, while the actual number of operations completed on any part is $\leq$ total number of operations.

c.3) A part once loaded on to a work station must complete its operation before it can be unloaded i.e. preemption is not allowed.

c.4) Parts arrive in a random manner with a known distribution of inter arrival times.

d) <u>Parts and Work Station</u>

d.1) There is negligible set-up time involved between two consecutive parts being worked on a machine, it can be included in the operation time of that the operation.

d.2) Change in machine assignment to a part is not possible, once it is assigned and transported to a particular work station. However in case of exception like machine break down, it is possible to assign and transport the part to alternative work stations if available.

3.3 CONTROL STRATEGIES:

The performance of a simulation model and also of actual FMS depends very greatly on the control strategies used in its operation. Hence a number of control strategies have been incorporated in the model to be applied at various decision points. These strategies can be grouped into four sections as follows.

(i) Rules for scheduling of parts for machine loading, transportation.

(ii) Strategy for selection of successive operation.

(iii) Strategy for machine selection for an operation, and

(iv) Strategy for control of movement and allocation of transportation devices.

3.3.1 Rules for Scheduling:

The following are the types of decisions to be taken while scheduling:

(i) Introduction of parts into the system.

(ii) Selection of jobs for machining.

(iii) Selection of Jobs for transportation.

Following simple and often used scheduling rules have been incorporated in this model to aid in decision making in the above environments.

(i) First come first served (FCFS): By applying this rule a job which arrives at first to the decision point is chosen.

(ii) Shortest Imminent process time (SIOT): Here a job whose imminent operation time is the least, is selected.

(iii) (Absolute) Shortest remaining process time (ASRPT): By this rule, a job which has the least remaining processing time is selected.

(iv) (Fractional) Shortest remaining process time (FSRPT): This selects a job having least remaining processing time as a fraction of total processing time.

(v) Earliest due date (EDD): This rule selects a job whose due date is nearest.

(vi) Least slack time (LST): This rule selects a job which has the highest urgency.

(vii) Longest cumulative waiting time (LCWT): By applying this rule a job which has highest value of occumulated waiting time is selected.

Whenever applying any of these rules a tie may occur. This is either broken arbitrarily or a hierarchy of rules may be established for the purpose.

3.3.2 Strategy for Selection of Successive Operation:

This is another decision point which arises owing to the process flexibility characteristic of FMS.

Here when there is no alternative for next operation to be performed on the job, the next operation is selected automatically. However the strategy adopted for the selection of subsequent operation in case alternative exists is outlined as follows:

(i) Under normal operating conditions, when alternatives exist for subsequent operation that operation which gives the minimum remaining process time is selected.

In the case of a tie, that operation which could be completed earliest (after checking machine assignment), is selected.

(ii) In case of exception like machine break down, the subsequent operation is so chosen that, the sequence that follows does not require the service of break down machine. In case the check fails for both the alternatives then that operation whose machine requirement is not the same as break down machine is chosen. In case of a tie, strategy (i) is used for selection of operation.

3.3.3 Strategy for Machine Selection:

This is a very important issue in an FMS as it provides alternatives for machining centres. To resolve the issue in the event of alternatives the following strategy is adopted.

(i) Select the machining centre.

(ii) Apply the scheduling rule that is being used for machine loading to determine time required before the job being considered is loaded.

(iii) Repeat the step (i) and (ii) for all alternative machining centres.

(iv) Select the machining centre where the job can be loaded earliest.

(v) In case of tie while comparing the alternatives, resolve the tie using the following rules in that order.

(a) Select the machine which is nearest to the present location.

(b) Select the machine whose cumulative busy time is the least.

(c) Select the first machining centre.

3.3.4 Strategy for the Control of Movement and Allocation of Jobs and Transportation Devices:

The following heuristic rules have been used to control the flow of parts in the system.

(i) A part is to be transported from loading buffer only when there is a vacant space at the input buffer of the required work station.

(ii) A job is to be transported from the output buffer of one work station to the input buffer of its next work station as early as possible.

(iii) If the input buffer of a work station is full when a loaded cart arrives, it is to be taken to the nearest central buffer if it is present, otherwise the cart waits at the work station for unloading.

Whenever there is more than one type of transportation devices, the decision about their priority of utilisation should be established. In the present model transportation devices are utilised in the order robots and carts.

The priority established for the control of movement of carts is as follows:

(i) Transport ~~ma~~ a part from the present location.

(ii) Move the empty cart to the nearest work station whose output buffer is full.

(iii) Move the cart to the nearest central buffer location, if there is a part to be transported.

(iv) Move the cart to the loading station, if there is a part waiting for transportation and there is no cart stationed at that location.

(v) Remain stationed at the present location.

However in case of exceptions like machine break down cart shall have second priority to transport jobs from the input buffer of such a machine to alternative work stations. Hence the cart be moved to that work station.

In case of transportation by robot, priority is given to transport a job of the highest priority from among the jobs in the output buffer of all work stations within its reach, whose next work station also falls with in its reach.

3.4 EVENT DESCRIPTION:

In the model described so far, the system status changes at discrete variable time increments. Hence while simulating such a model, time control should be such that no details of the change in system status should be lost. In such cases discrete event simulation with next event scheduling approach proves an efficient way of simulation. In this approach there is no change in system status between any two consecutive events. The clock time of simulation and the system status are updated at the occurrance of each of the events occurring in the system.

In the model that has been developed, the following are the events that cause a change in the system status.

(i) Operation Complete: The completion of an operation performed at a work station on any job.

(ii) Job Arrival: The arrival of a job for processing in the system at the loading station.

(iii) Cart Arrival: The arrival of a cart at a station to either load or unload a part.

(iv) Robot Arrival: This is the completion of transportation activity by a robot.

(v) Break down: The occurrance of failure of a work station after which it becomes unavailable for use until repair completion.

(v) Reactivate: This indicates the completion of repair of the break down machine. The machine becomes available after this event.

These are the main events that cause a change in the system status. In addition to the above events, two more event types have been considered. Though these donot affect the simulation directly, they are used for graphics animation of the simulation process. They are:

(vi) System Calculation: This event causes an update of the positions of carts and robots in the system.

(vii) Graphics Display: This event causes display of the system status at that instant on the graphics screen.

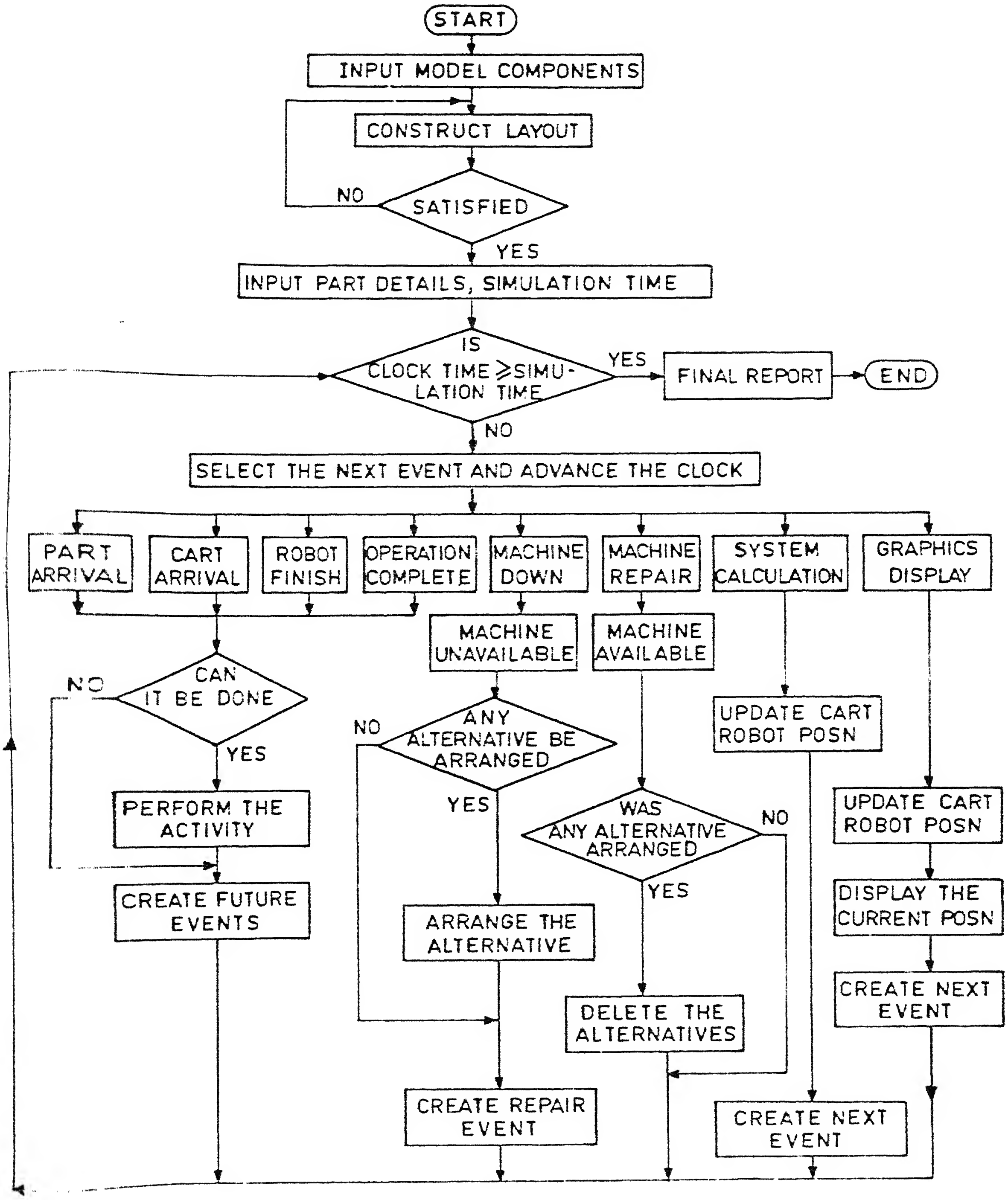


Fig. 2 Flow chart for simulation model for FMS.

3.5 PERFORMANCE MEASURES:

The criteria used for measuring the performance of a simulation model depends on the purpose simulation is used. The objective of the present model being development and evaluation of control strategies for FMS and the need for efficient control strategies is to achieve higher system productivity and utilisation, the measure of performance chosen is related to these aspects. They are:

(i) System Productivity Report: This collects data regarding total number of parts produced, production rate, average lateless per job.

(ii) Work Station Utilisation Report: This collects the data regarding the performance of work stations such as station busy time, idle time, number of operations performed.

(iii) Materials Handling System Utilisation Report: This gives details about busy time, idle time, total number of parts transported etc. by carts and robots.

To test the steady state of the system during simulation an average latness criteria has been adopted. According to the criteria, average lateness per job is measured for jobs completing their operations in each interval and this is compared with the cumulative average lateness per job for all finished jobs upto that interval. The model is said to have reached steady state when the deviation between these two values is less than a certain limit.

The next chapter gives details about implementation of this model.

CHAPTER IV

IMPLEMENTATION OF THE MODEL

The model developed in the previous chapter has been implemented in Pascal. This implementation includes graphics animation facility. Though the implementation in general can be used in Pascal environment, the animation part makes use of the terminal features of Tektronix 4107/4109 terminals. This chapter outlines the general features about implementation with some details about the working of different modules.

4.1 SOFTWARE CONFIGURATION:

The software configuration of the simulator developed in this work is summarised in the Figure 2. The simulator is composed of three subsystems. Namely,

(i) Data input subsystem

(ii) Execution subsystem and

(iii) Animation and report generation subsystem

Each of these subsystems consist of several modules which inturn are divided into several procedures. The overall program of this simulator is developed in a structured manner as hierarchially as possible to facilitate flexibility easy modification and extension of the simulator. The details about various subsystems is presented in the following sections.

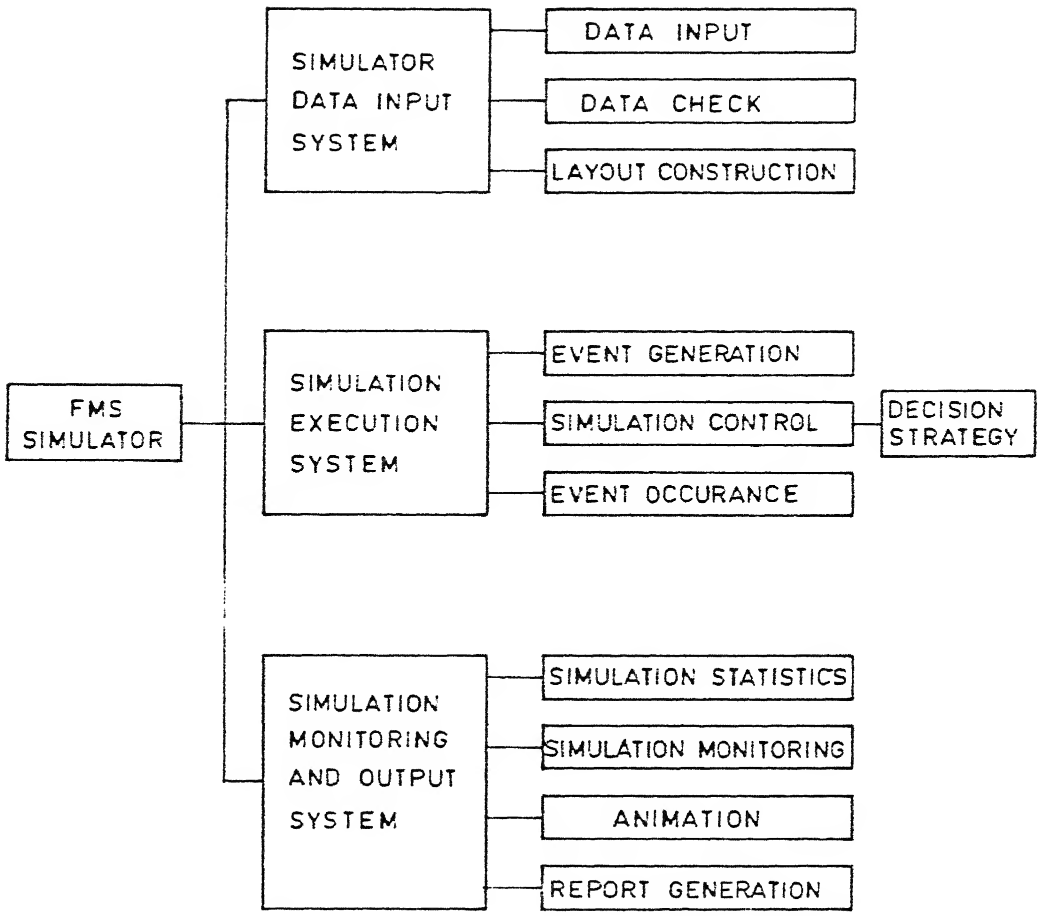


Fig. 3 Software configuration of the simulator

4.2 SIMULATION DATA INPUT SUBSYSTEM:

This system consists of two modules. Namely,

(i) Input module

(ii) Layout construction ~~a~~ module

4.2.1 Input Module:

This module accepts data from the user about the system characteristics. The input can be given either interactively through the key board or can be read from an input file. This module consists of the following procedures.

(i) Model Input (Procedure MODEL_INP): This procedure accepts data about the components of the model such as number of work stations, buffer capacity, number of carts etc.

(ii) Part Detail (Procedure READDATA): This procedure takes details about parts that are to be produced in the system. The data such as number of part types, number of operations required on the part type, sequence of operations, machines required, and alternatives for operations and machines, if any, are read in this procedure.

4.2.2 Layout Module:

This module accepts data about the topology of the system. This module consists of the following procedures.

(i) Conveyor Track Details (Procedure TRACK_DET): This procedure accepts details about the tracks such as number of segments of the conveyor, their locations etc. Here data is checked for input error and user is informed accordingly.

(ii) Station Details and Location (Procedure ST_LOCATION): In this procedure, the following details are enquired from the user:

(a) Station Type: Machining centre, central buffer, loading station or unloading station,

(b) Station location, and

(c) Location of input and output buffers i.e. track segment by which the station is served.

4.3 SIMULATION EXECUTION SUBSYSTEM:

This is the main body of the simulator and consists an event module and a control module. Event module is responsible for execution of occurred event and creation of future events. Control module is responsible for organising the events in a chronological order, and managing the status information of the system. This also includes logic for monitoring the components of the model such as machines, carts, robots and parts that are being processed in the system. These modules are described in the next section.

4.3.1 Event Module:

This module consists of two sections:

(i) Event generation section and

(ii) Event execution section.

(a) Event Generation Section:

The procedures that constitute this section are invoked every time an event execution occurs. This section consists of the following procedures.

(i) Work Station Loading (Procedure IDMC): In this procedure an event of type operation complete is created. Here the status of all work stations is checked and a job if present in the input buffer is loaded on to the idle machine otherwise it remains idle. Selection of job for loading is done by the control module after computing the priority.

(ii) Cart Loading (Procedure CART-FREE): This procedure creates an event of type cart arrival. Here the priority as established in the section 3.3.4 is followed. In this case also selection of job for cart loading is done by the control module.

(iii) Robot Loading (Procedure ROBO_FREE): This deals with loading of robots. This procedure determines the job to be loaded from among the high priority jobs that are present at the stations served by the robot.

(iv) Machine Break Down Generation (Procedure GEN_MC_DN): This procedure creates an event of type break down when specified by the user.

(b) <u>Event Execution Section</u>:

These procedures advance the system clock and execute the corresponding event.

(i) Job Arrival (Procedure JOB_ARR): This procedure signals the arrival of job at the loading station. At this stage, the following attributes part type, arrival time, due time are assigned to the job. This procedure creates another event of same type.

(ii) Operation Completion (Procedure MC_COM): In this procedure, a job which has completed its operation is unloaded and stored in the output buffer if it is vacant. The machine status is changed to idle and available if the job is unloaded otherwise it is changed to idle and unavoidable.

(iii) Cart Arrival (Procedure CART_ARR): In this procedure the cart is unloaded if it is carrying a part and the buffer is vacant. Then the cart status is changed to available, otherwise decision is taken to send the cart to the central buffer if it is a part of the system or else the cart status is changed to waiting.

(iv) Robot Arrival (Procedure ROBO_FINISH): This procedure deals with the transportation by a robot and it works in the same way as in cart arrival.

(v) Machine Break Down (Procedure MC_BRK_DN): This procedure is invoked when a break down event occurs. Here the user specifies whether the alternative work stations can be arranged and those changes in the machine assignment to part types is done here. This also creates an event of type machine repair in the process.

(vi) Machine Repair (Procedure REACTIVATE): This procedure changes the break down machine status to available and alternative arrangements are deleted for further assignment.

(vii) System Position Calculation (Procedure SYS_CAL): This deals with the calculation of position of robots and carts for the purpose of animation. This will be dealt in detail in the Sec.4.4.

This procedure creates another event of same type.

(viii) Graphics Display (Procedure GR_DIS): This procedure deals with the display of current status of the system. This will be dealt in detail in the Sec. 4.4 . This creates an event of same type.

4.3.2 CONTROL MODULE:

This module forms the logic part of the simulator. This section deals with the following activities.

(i) Selection of successive operation.

(ii) Machine selection.

(iii) Parts selection for machine loading.

(iv) Parts selection for loading of carts.

(v) Control of movement of transportation devices.

and (vi) Organising the events.

They are outlined below.

(i) Operation Selection (Procedure SEAR_OPN): This procedure uses the priorities described in Sec. 3.3.2 for operation selection whenever choice is available.

(ii) Machine Selection (Procedure SEAR_MC): This procedure implements the logic outlined in Sec. 3.3.3

(iii) Parts Selection for Machine Loading (Procedure HIPRIPB): This procedure select the jobs using the priority rule assigned by the user. This procedure provides a hierarchy of rules for the purpose in the event of a tie.

(iv) Part Selection for Cart Loading (Procedure HIPRIOPE, HIPRILEF, HIPRINTE): These procedures use rules as specified by the user for the purpose. But cart loading at the loading buffer is by FCFS rule always. At intermediate buffers parts are arranged according to priority and are selected in that order only.

(v) Movement Control of Carts (Procedures MOVEML, MOVEINTE, MOVELDB): These procedures utilise the logic described in the Sec. 3.3.4 to control the movement of carts in the system.

(vi) Organising Events (Procedure INSERT): This procedures maintains a list of events and the records in the chronological order. Always an event at the head of the list is the imminent event.

4.4 ANIMATION AND REPORT GENERATION:

This subsystem consists of three modules.

(i) Animation module,

(ii) Monitoring module, and

(iii) Report module.

The objective of this system is to increase the understandability of the simulator. Especially graphics animation capability is significant for the user to understand the simulation process. A topology of system layout and dynamic movement of parts, carts, robots through the system are displayed on a graphics display terminal. On the other hand simulation monitoring module allows the user to obtain intermediate simulation

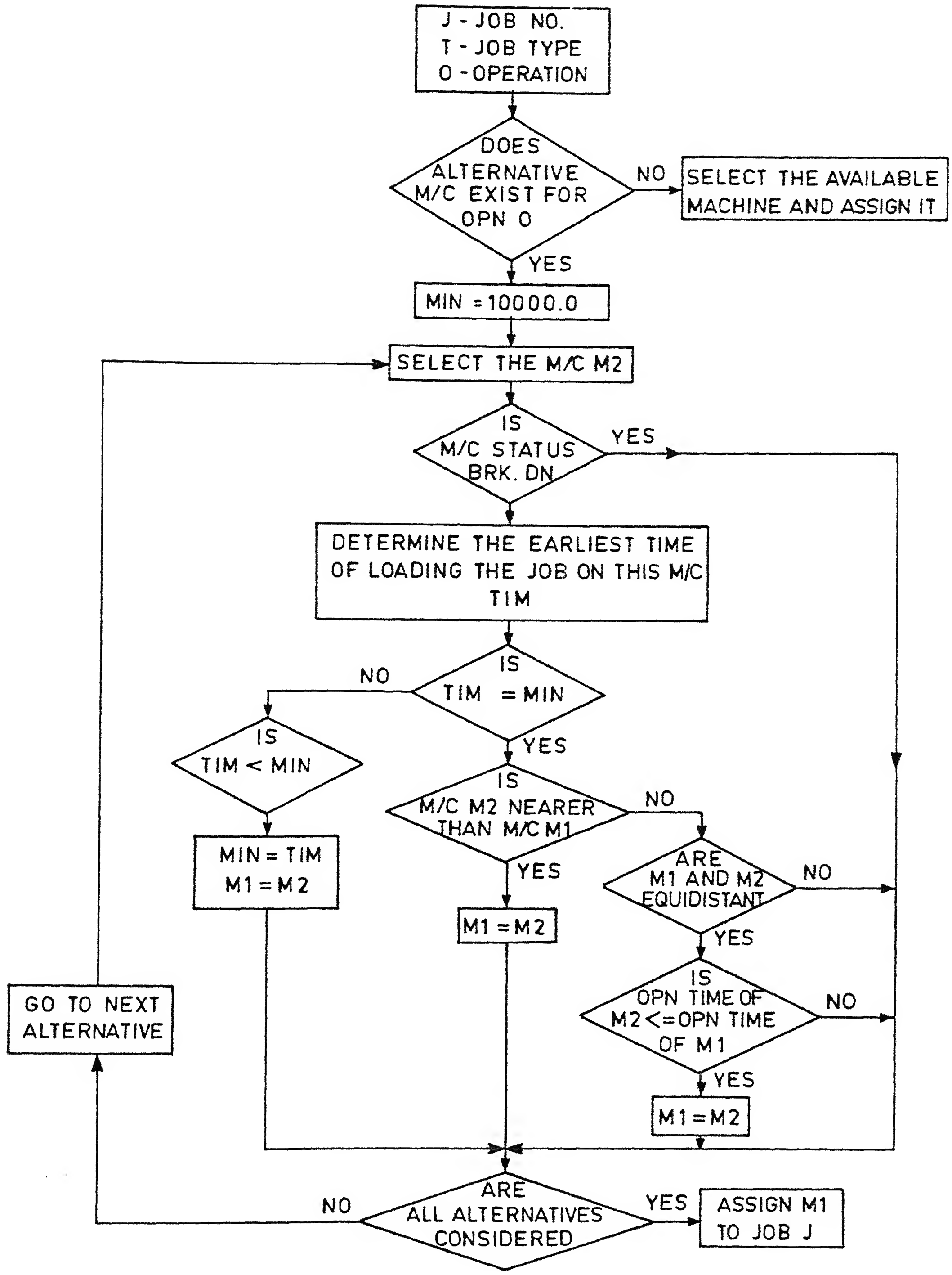


Fig. 4 Flowchart for machine selection.

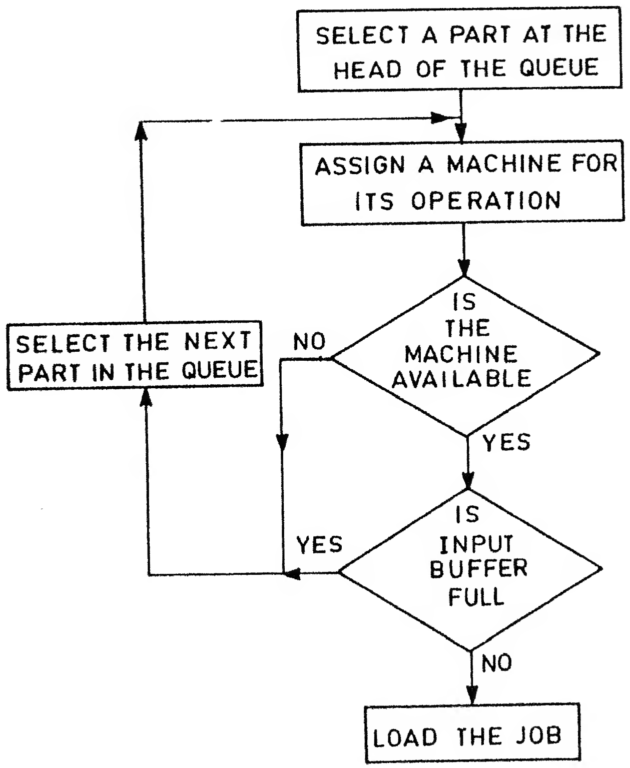


Fig. 5(b) Flowchart for job selection for transportation at loading buffer and central buffer.

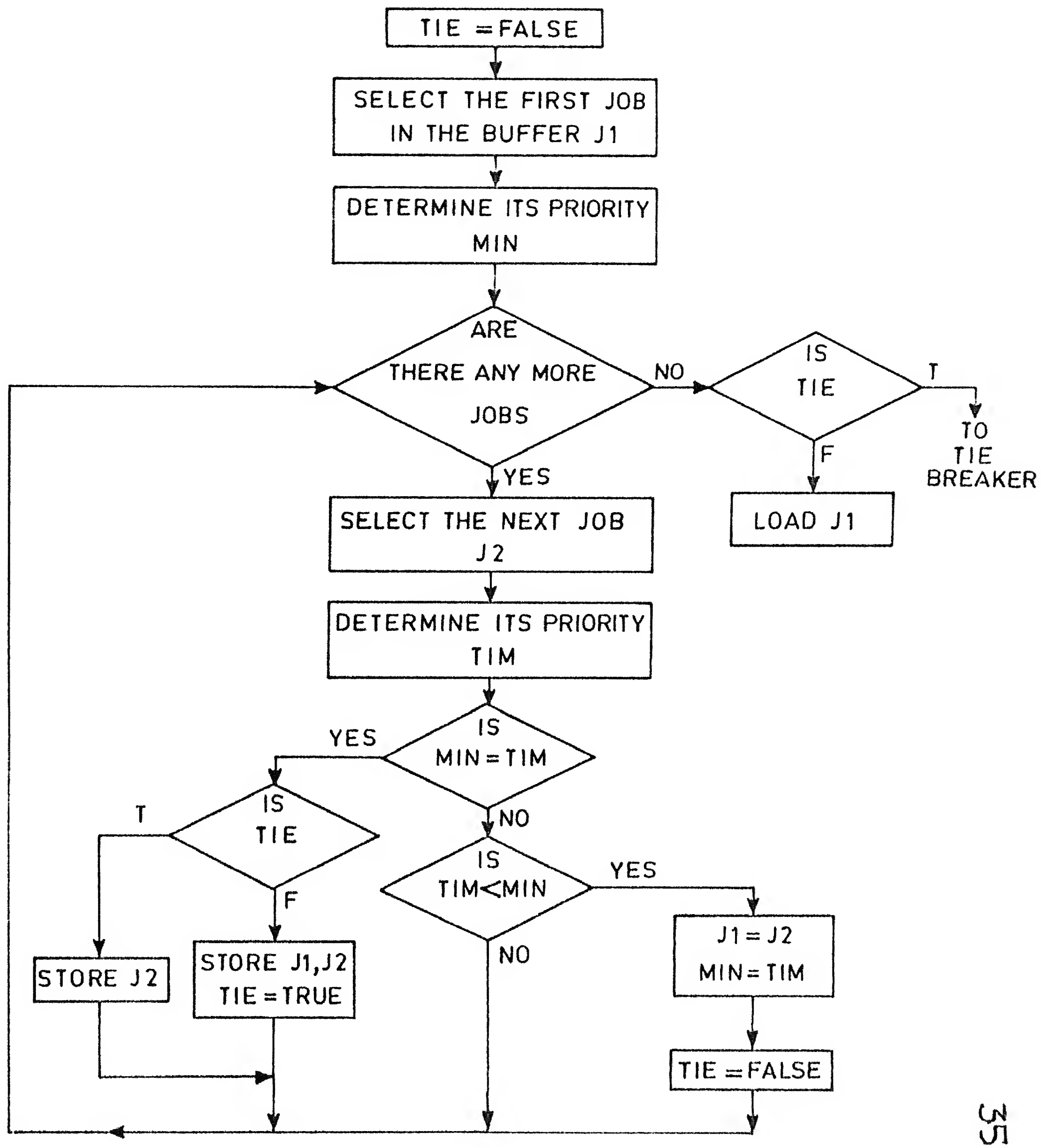


Fig. 5(a) Flowchart for Job selection for machine loading and transportation at work stations.

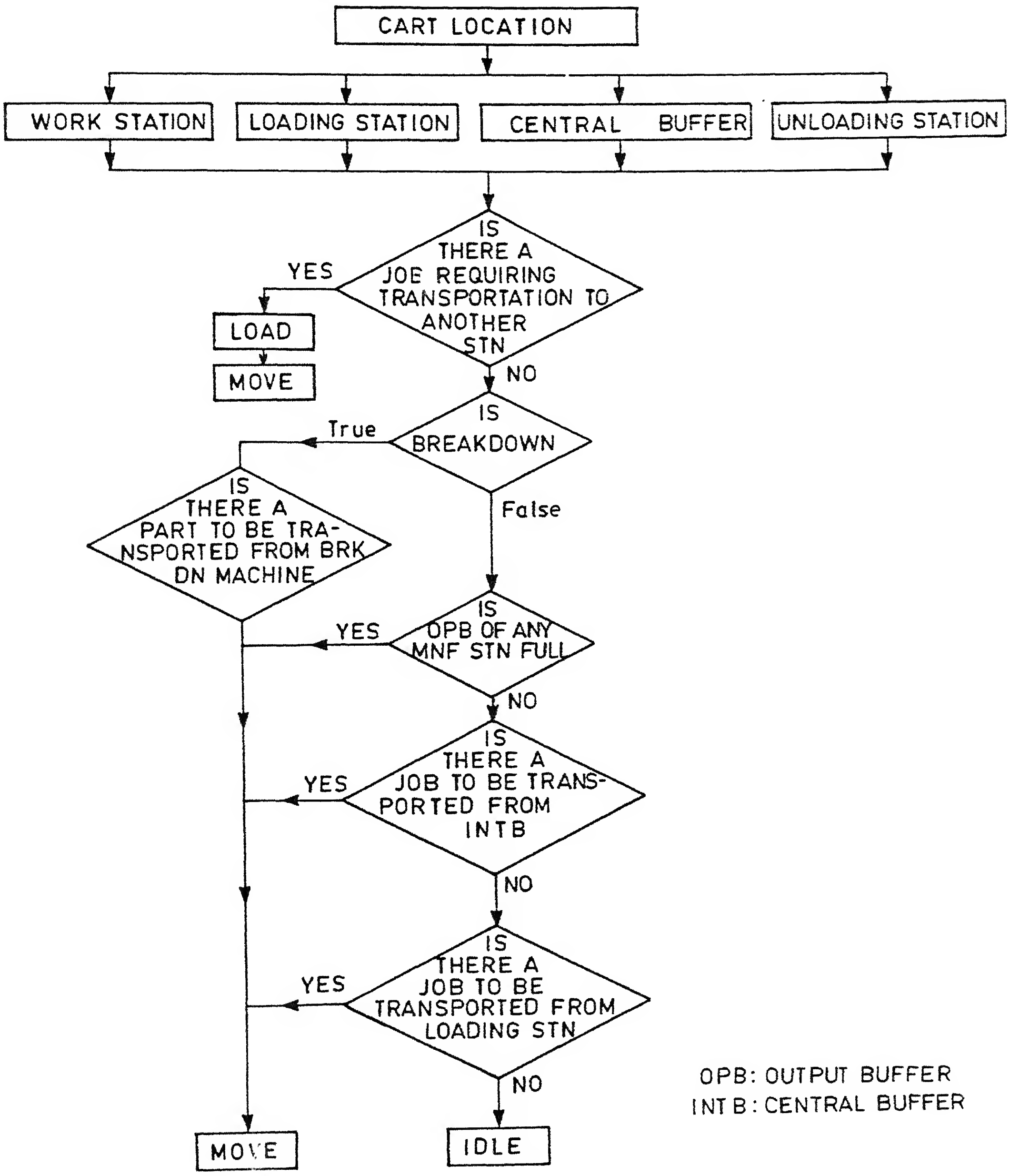


Fig. 6 Flowchart for control of movement of carts.

results if desired. The report module is responsible for providing the final simulation results in the form of tables. The details about these modules are outlined below.

4.4.1 Animation Module:

This module can be considered in two sections.

(i) System calculation section and

(ii) Graphics display section.

(i) System Calculation Section:

This section is invoked at frequent intervals by occurrance of event type system calculation (Sec. 3·4). This section determines the position of carts and robots. The procedures in this section are:

(a) Calculation of Cart Position (Procedure (CART_LOCATION): This procedure determines the current position of the cart and also its direction of movement, making use of its previous position, direction and present status. This procedure with the help of several other procedures determines the current position, checks whether it has exceeded the track segment limit, if it has finds the direction and track segment on which it should be positioned (Procedures FIND_TRACK, MOVING_LFT, MOVING_RT etc.).

(b) Calculation of Robot Position (Procedure ROBO_TRANS): This procedure finds the position of robot. The direction of movement of the robot is determined every time its movement begins. Current position of the robot is determined with this information and robot speed of movement.

(b) Graphics Display Section:

This section displays the position of carts and robots at frequent intervals. This section is invoked by the occurrance of the event of type graphics display. Carts are represented as triangular blocks in the display. This gives clearly their direction of movement also.

This section consists of the following procedures.

(i) Topology Display (Procedure STN_DRAW, TR_DRAW): These procedures display the stations and track segments. Stations of different type are clearly marked with different colours.

(ii) Movement Display (Procedure CRT_DRAW, SYS_DRAW): These procedures display dynamic movement of carts and robots. Robot at the rest position is shown as a small rectangular block and while moving it is shown as enlarged and rotating about a base.

4.4.2 Monitoring Module:

This module provides the user a facility to interrupt the model during the simulation run and obtain intermediate results. This module also provides the user with a menu (see App. B) and an option to modify the parameters, change scheduling rules etc. This section consists of procedures to display graphical outputs about system performance. This includes number of parts of different types produced in the system (Procedure PART_CHART), machine utilisation, number of operations completed at each machine, (Procedure MC_CHART), carts utilisation (Procedure CART_CHART), and robot utilisation (Procedure ROBOT_CHART).

The graphical output also gives number of parts transported by each cart and number of parts transported by each robots.

4.4.3 Report Module:

This module prepares reports about the system performance. These reports can be obtained at users request and can also be obtained at the end of the simulation run. This consists of several procedures as given below.

(i) Analysis (Procedure ANALYSIS): This gives details such as total number of parts entering and leaving the system, number of parts of each type produced, machine utilisation, cart utilisation and robot utilisation.

(ii) Job Details (Procedure JOB_STATS): This procedure gives such details about finished parts as job no., job type, arrival time, due time, exit time, time spent, process time, waiting time and lateness.

(iii) Detailed Output (Procedures CART_DET, MC_DET etc.): These procedures give details about individual components of the system. This includes the following:

(a) For Part Types: production rate, average lateness, and number of parts produced.

(b) For Machines : Production rate, number of operations completed, block time, idle time and busy time.

(c) For Carts: Busy time, waiting time, idle time and number of parts transported.

(d) For Robots: Busy time, waiting time, idle time and number of parts transported.

CHAPTER V

SYSTEM VALIDATION AND OUTPUT ANALYSIS

The scheduling problem in FMS is complex, owing to the number of variables affecting the system performance. Hence while considering the validation of a model, a number of factors are to be taken into account about the configuration and operation of FMS. They are discussed in the following section.

5.1 SYSTEM DESIGN:

The system considered for experimentation has the following characteristics.

(a) Size of FMS: The case studies of several existing FMS installations world wide reported by Annborn. M., Romanini. S., and Schmoll. P., and Popplewell. F., (1984) says that the minimum number of machining centres in an FMS is five. Ranky (1983) recommends that the best policy to investigate an FMS is to include about five machining centres.

Hence, with this in view six machining centres will be included in the system under study.

(b) Number of Part Types: As reported by Boer. C.R. and Melkanoff. M.A., most of the existing FMSs in the world are capable of taking 3 to 10 part types.

In the system under study, six part types have been included.

(c) Arrival Rate: Based on the commonly used distribution of random arrivals, an exponential inter-arrival time is selected. An average inter arrival time of 12 minutes is chosen.

(d) Due Date: For the assignment of due date to arriving jobs TWK method (assigning due date based on total work content) as suggested by Conway (1967) has been adopted. According to this method,

$$D_i = A_i + KP_i$$

where,

D_i - due date for job i

A_i - arrival time of job i

P_i - total processing time of job i

K - parameter specified by management

In the present study, parameter K has been chosen as four.

(e) Scheduling Period: The scheduling period chosen is 12 hrs. This period was chosen so as to allow the system to reachk the steady state as far as possible.

(f) Materials Handling System: Variations in the components of materials handling system have been examined. However, the speed of cart movement has been kept constant and is equal to 4 m/min. The speed of movement of robot is2 20°/min.

(g) Buffer Capacity: The capacity of input and output buffers has beent taken as equal and they are capable of storing four parts each.

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(g) Buffer Capacity: The capacity of input and output buffers has been taken as equal and they are capable of storing four parts each.

5.2 DESIGN OF EXPERIMENT:

The experiments will demonstrate the effectiveness of scheduling strategies on the system performance under various system configurations.

The scheduling rules outline in the section 3.3.1 have been used and the following strategies as given in the Table 1 have been investigated.

Table 1: Strategies for scheduling.

Strategy	Decision Points	
	Machine loading machine assignment	Loading MHS
1	Shortest imminent operation time	Longest cumulative waiting time
2	(Fractional) shortest remaining process time	Least slack time
3	Least slack time	(Absolute) shortest remaining process time
4	Longest cumulative waiting time	(Fractional) shortest remaining process time
5	Shortest imminent operation time	Least slack time

Experimental runs were conducted for the above scheduling strategies with variations in materials handling system and storage system. These are outlined below.

Case a) Variations in MHS and storage system, with alternatives for machine assignment.

Expt. 1: MHS consists of two carts and a robot. Storage system does not have a central buffer.

Expt. 2: MHS consists of three carts and a robot. Storage system does not possess a central buffer.

Expt. 3: MHS consists of four carts only. Storage system does not have a central buffer.

Expt. 4: MHS consists of four carts. Storage system includes a central buffer.

Case b) In this set of experiments, the alternatives for machine assignment is removed. Here the following system configurations were investigated.

Expt. 5: MHS consists of four carts. Storage system does not include a central buffer.

Expt. 6: MHS consists of four carts. Storage system possesses a central buffer.

One more experiment was conducted with the same system configuration as in expt. 4, by changing the random number stream.

The results obtained from these experiments have been tabulated and analysed in the next section.

5.3 OUTPUT ANALYSIS:

The system performance characteristics from the above experiments have been presented in Tables 2 and 3.

Table 2 lists average machine utilisation, average cart utilisation, and robot utilisation.

Table 3 lists total number of finished jobs, average lateness per job, and number of jobs that have been able to meet the due date as a fraction of the total number of finished jobs.

Table 5.2: Average System Utilization.

Strategy	Expt.	1	2	3	4	5	6	7
1	a	0.4731	0.6543	0.6385	0.7091	0.6046	0.6313	0.5683
	b	0.8135	0.7670	0.6185	0.7135	0.5835	0.7190	0.5413
	c	0.2230	0.3200	-	-	-	-	-
2	a	0.4688	0.6193	0.6300	0.6456	0.5740	0.6132	0.5750
	b	0.8165	0.7446	0.6547	0.4705	0.5960	0.5030	0.5420
	c	0.2110	0.2970	-	-	-	-	-
3	a	0.4880	0.6230	0.7035	0.6962	0.5740	0.6383	0.5890
	b	0.8475	0.7740	0.7343	0.7433	0.5602	0.7100	0.5875
	c	0.2220	0.2600	-	-	-	-	-
4	a	0.477	0.6288	0.6600	0.6785	0.5625	0.6256	0.5712
	b	0.8410	0.7650	0.6815	0.7250	0.5635	0.7065	0.5575
	c	0.2190	0.3030	-	-	-	-	-
5	a	0.4726	0.6470	0.6182	0.6976	0.5930	0.6214	0.5672
	b	0.8265	0.7450	0.6225	0.7128	0.5560	0.5730	0.5250
	c	0.2260	0.2890	-	-	-	-	-

Legend: a - average machine utilisation
b - average cart utilisation
c - average robot utilisation

Table 5.3: System productivity.

Strategy		Expt. 1	2	3	4	5	6	7
1	a	36	55	50	54	44	37	46
	b	83.93	58.80	42.89	36.23	60.46	50.13	34.95
	c	0.25	0.36	0.46	0.39	0.41	0.59	0.56
2	a	35	50	52	46	46	35	48
	b	63.78	62.72	51.32	31.97	58.46	50.34	30.52
	c	0.34	0.34	0.40	0.52	0.41	0.60	0.52
3	a	38	49	54	56	38	38	48
	b	89.52	63.10	41.13	38.32	61.45	46.63	33.00
	c	0.13	0.10	0.27	0.19	0.31	0.28	0.37
4	a	34	49	51	47	43	36	46
	b	93.78	49.85	46.24	39.93	62.39	47.41	35.73
	c	0.15	0.20	0.22	0.32	0.28	0.37	0.59
5	a	37	53	48	55	42	36	46
	b	74.18	47.36	43.82	33.11	60.13	38.25	34.46
	c	0.32	0.38	0.35	0.36	0.45	0.56	0.54

Legend: a - total number of jobs finished
b - average lateness per job (min.)
c - fractional finished jobs meeting the due date

The results indicate the influence of scheduling strategies on the system performance. The results show a wide range of variation with different configurations of the FMS.

The experiments were terminated after 720 minutes of clock time. It has been observed the system reached steady state in some cases.

It is often insufficient to draw any conclusions about the effectiveness of scheduling strategies on the system performance with few runs. However, certain comments can be made about it, from the results obtained.

It can be noted from the experiments 3 and 4 (Table 2), that the presence of central buffer has resulted in a lesser average lateness per job than when it is not present. Also in this case utilisation of transportation devices is higher.

Experiments 5 and 6 demonstrate that the possibility of alternative machining centre has resulted in a higher throughput of the system. This is quite understandable since machine assignments are made in such cases at the required moment only, taking into account the possibility of earliest completion of that operation. This has resulted in higher average machine utilisation also (Table 2).

Coming to the performance of the system under variations in MHS (Expts. 1,2 and 3), it can be observed that there is wide variation under different control strategies. For example, strategy 3 has resulted in higher throughput in experiment 1 and

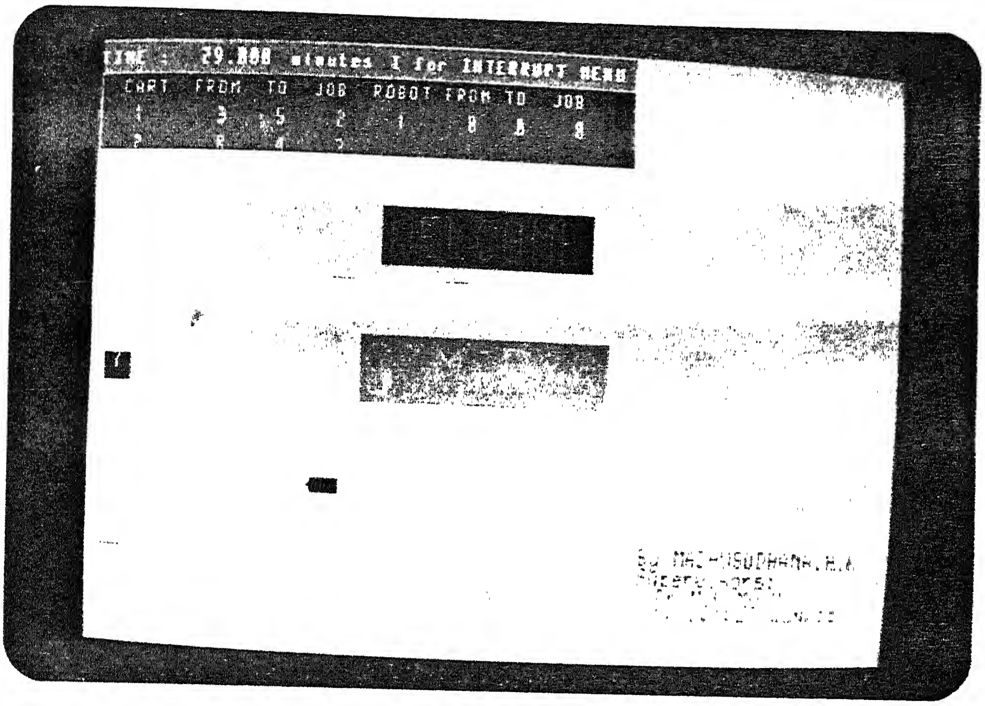

Figure 7 Photograph shows lay out display of an FMS

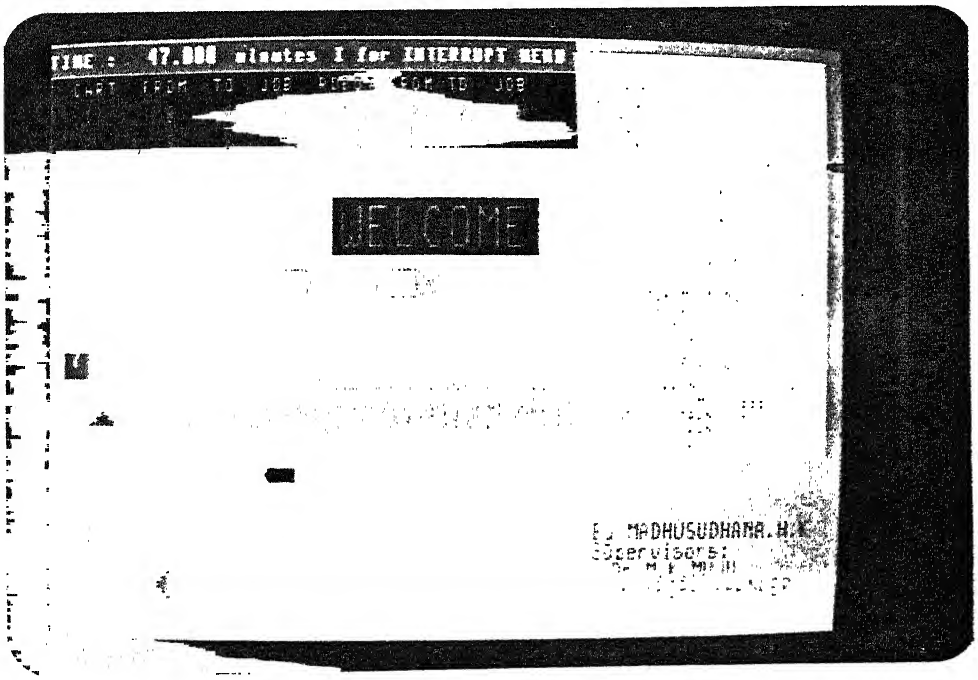

Figure 7. photograph shows the MENU options available

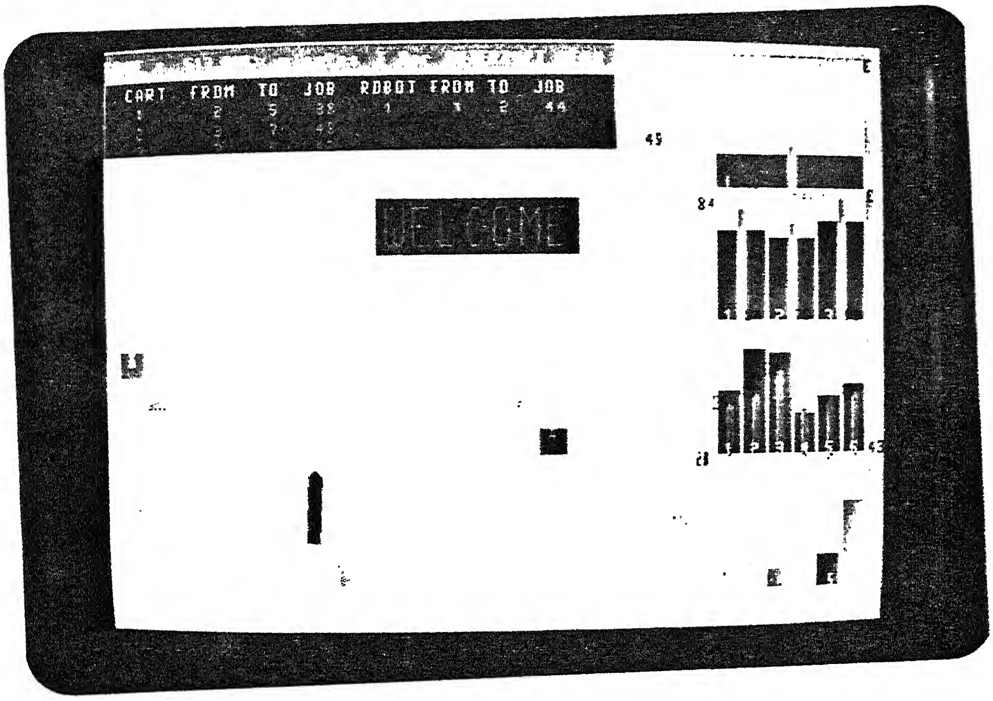

Figure 7 photograph shows display of graphical output (charts) during simulation

experiment 3 where as strategy 1 has given a higher value of throughput for experiment 2 (Table 3).

Hence it is necessary to investigate the system under variation of different parameters thoroughly before drawing any significant conclusions.

The experimental runs investigated above demonstrate the complex behaviour of an FMS and the number of parameters affecting it. In order to determine the most effective strategy for any particular configuration of FMS, experiments may be conducted along similar lines and conclusions may be drawn from the results obtained.

CHAPTER VI

SUMMARY

6.1 CONCLUSIONS:

Simulation is an effective technique for studying the behaviour of a complex system like an FMS. The simulation model can be used for studying the effectiveness of different scheduling strategies for the performance of an existing or proposed FMS.

Animation of material flow along with simulation monitoring system through interrupt menu provides an effective way to simulate variations several parameters on an FMS. Animation helps in better understanding of the system.

Though the package incorporates only six scheduling rules, new ones could be added easily by the user for thepurposes of evaluation. The facility provided through menu system could be used to simulate what if scenarios by the user, in the operational control of an FMS.

The model building by the user through this package is done interactively and the input of data does not require any knowledge of simulation.

The package provides facility to generate machine break down, externally which can be used to simulate future schedules in the

operational control of an FMS.

6.2 POINTERS TO FURTHER DEVELOPMENT:

The results from experiments designed to validate the model indicate the complex behaviour of FMS. Experiments may be conducted more critically, along the same lines for steady state performance of the model. This may lead to the determination of effective scheduling strategies and through more light on the capabilities and weaknesses of the model, leading to further refinement.

Further development of the model could be in the following areas:

(i) Consider machine break down as a parameter of the model using known distribution of failures and MTBF.

(ii) The materials handling system of the model could be enhanced to include open loop conveyor system, AGVs etc.

(iii) An interface can be developed for initial assignment of machines for each part types, depending on the operation tool required, tool availability and tool distribution. This module may be used in conjunction with present package to determine optimal tool distributions. By incorporating such a module it is possible to include such events as tool breakage, tool life completion etc. for simulation.

(iv) By developing a module for coding and classification of parts, it is possible to evaluate the effectiveness of part-family concepts on the system performance.

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USER'S MANUAL

This manual is intended to give users an introduction to the simulator developed in this work. This manual gives details about the utilities of the simulator in the following sections.

i) Simulator Capabilities

ii) Input to the Simulator

iii) Simulation Monitoring, and

iv) Simulation Output.

These are described below.

i) Simulation Capabilities:

The simulator can accomodate the following components.

(a) Work Station: There can be a maximum of twenty-five work stations.

(b) Loading and Unloading Stations: There has to be separate loading and unloading stations. In case they are located physically at the same location, they are to be given individual station numbers (see below) for the successful working of the simulator.

(c) Central Buffer: Semi-finished parts are stored here during transit. There can be a maximum of two such locations.

Each of these locations are referred to as stations in the simulator. These stations should be numbered in a clockwise or anti-clockwise direction.

(d) Material Handling System: The consists of conveyor and robots.

(d-1) Conveyor System: The conveyor system forms a closed loop and consists of horizontal and vertical straight line segments. Maximum number of such segments should be less than 20. These

segments should be numbered in clockwise or anti-clockwise direction. Each segment is indicated by a pair of coordinates X1,Y1 and X2,Y2. These are denoted like this.

X1,Y1: denote coordinates nearer to XY axes.

X2,Y2: denote coordinates farther from XY axes.

Loading and unloading at any work station is possible on only one track segment.

(d-2) Robot: The simulator can accomodate a maximum of ten robots in FMS. These robots can serve work stations only. A work-station may served by more than one robot. Robot location is the point about which its arm rotates.

(e) Parts: The simulator can accomodate twenty part types. Each part type may not have more than 15 operations. Care should be taken to avoid assignment of same work station for successive operations, this may result in errors.

ii) Input to the Simulator:

Input to the simulator may be given interactively using key board or may be read through input files. The user is to specify the file name from which it is to be read. In case of interactive input, file name to be given is Term . The user is suggested for giving inputs in interactive mode.

The input format in case of reading the data through a file is given below.

(a) Model Components:

Number of work stations, input buffer capacity, output buffer capacity

Number of carts, cart-speed.

[Details regarding central buffer, and robot is to be given interactively.]

(b) Layout Construction:

Xmax, Ymax: Maximum size of layout.

(b-1) Track Details:

Number of segments

X1, Y1, X2, Y2

. . . .

. . . .

(b-2) Station Location:

X, Y, T1

. . .

. . .

T1: Track number by which the station is served.

(c) Part Details:

The operations required on a particular part, Type are to be numbered starting with the first operation to be performed as one.

Average inter arrival time.per [illegible] as

Number of part types

Opn

Mc	A1	Altmc	Nextopn	Alt	No of alt	Altopn	
.	.	.	.	.	.	.	for Operation 1
.	.	.	.	.	.	.	for Operation 2
.	.	.	.	.	.	.	for Operation Opn

Pr

where,

Mc: Station number of the required workstation.

A1: Number of alternative work stations if present.

Altmc: Alternative work stations (station no.)

Nextopn : Subsequent operation number

Alt : 1 if alternative present else 0

No. of alt: Number of alternatives present

(Presently this is limited to 1)

Altopn : Operation number of alternative opn.

Pr : Probability that a part arrived is of this type.

iii) Simulation Monitoring:

This section gives details about thefacilities provided in the simulator. The simulator provides an interrupt menu so that the user may interrupt the simulator during simulation run and get the necessary information. This menu offers the following facilities.

(a) User may change the graphics display interval. This change occurs from the time of next occurance of display event.

(b) He/can change the scheduling strategies at the middle of simulation run. The change done is recorded in the output file accordingly. The user is provided with a priority menu at this point giving the scheduling rules available and as well as the current choices.

(c) He can get the intermediate results about the system performance in the form of graphs. This gives such details as number of parts of each type produced, machine utilisations, number of operations done, cart, robot utilisation, number of parts transported etc.

(d) He may increase the simulation time - clock time for which the simulation is to be run.

(e) He may get detailed performance report about the system performance.

(f) He can generate machine break down event to study the system performance under disturbance.

(g) He can change average inter arrival time to study sudden rush or lean period performance.

iv) Output of Simulator:

The output of simulation is recorded in an output file. User is required to create a file OUT for the purpose.